

# **Tunable Low Noise Amplifier**

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## **Related Applications**

This application claims the benefit of U.S.

5 Provisional Application 60/283,093, filed April 11,  
2001, which is hereby incorporated by reference. In  
addition, this application relates to U.S. applications  
09/904,631 filed on July 13, 2001, 09/912,753 filed on  
July 24, 2001, 09/927,732 filed on August 8, 2001,  
10 09/927,136 filed on August 10, 2001, "Tunable  
Capacitor," filed on January 11, 2002, and "Antenna  
Interface Unit," filed on February 8, 2002, which are  
hereby incorporated by reference.

## 15 **BACKGROUND**

Wireless communication devices, such as, but not  
limited to, wireless telephones, use many electronic  
components to transmit and receive signals over the  
20 air. A transceiver is the part of a wireless telephone  
that actually sends and receives signals. The front end  
of a transceiver is the portion of a transceiver  
closest to the air interface in the signal path. The

front end includes an antenna and several components near the antenna in the signal path. Several of the components required in the front end of the transceiver are power amplifiers (PA's), isolators, low noise  
5 amplifiers (LNA's) and multiplexers. Each of these components are typically manufactured as packaged devices. In the case of a PA or an LNA, this package typically includes the active device and internal input and output matching circuits for bringing the input and  
10 output resistances up to an industry standard 50 ohms.

In one common embodiment, the packaged PA is comprised of a high performance FET (e.g., GaAs) placed on a ceramic or other substrate. Other active devices can be used, such as, for example, bipolar junction  
15 transistors (BJT's) and high electron mobility transistors (HEMT's). The matching circuits may be patterned on the ceramic substrate, or they may be fabricated using lumped surface mount technology (SMT) components. The FET is bonded to the package substrate,  
20 possibly to a metal heat sink, then typically connected to its input, output and bias pads using bond wires.

Depending on the requirements, multi-stage PA devices may be used as well. This means that one PA

device may include more than one amplifying transistor. This may be necessary for a number of reasons. One possible reason is to produce the required gain. In the case of a multi-stage PA device, inter-stage impedance  
5 matching circuits may be used as well, to match between the output of one stage and the input of the following stage.

The inputs, outputs and bias lines to the FET are routed down to the ceramic substrate. After passing  
10 through the matching circuits, the input and output lines are routed off of the substrate down to the underlying printed wire board (made of FR-4 in most cases) through connectors on the PA package. Further wire bonding may be required to connect the package  
15 pads to the input, output and bias lines.

The package further comprises some kind of packaging (typically polymer) encasing, in whole or in part, the FET and the ceramic substrate holding the matching circuits. The input and output bias leads can  
20 be found at the edge of the packaging.

Isolators, duplexers, diplexers and low noise amplifiers (LNA's) are handled in much the same way. As packaged devices, they each have their separate

substrates with their separate matching circuits  
bringing their input and output impedances to 50 ohms.

Most RF test equipment can only test parts at an  
impedance of about 50 ohms. Manufacturers and designers  
5 typically want to be able to test each part separately.  
Historically, the only way this could be done was if  
each part had input and output impedances of around 50  
ohms. For this reason, parts, such as PA's and LNA's,  
for example, have typically been manufactured with  
10 impedances equal to about 50 ohms. This has required  
the use of extensive input and output matching circuits  
for many of these parts.

A duplexer is one of the primary components in a  
transceiver front end. The duplexer has three ports (a  
15 port is an input or an output). One port is coupled to  
an antenna. A second port is coupled to the transmit  
signal path of the transceiver. The duplexer couples  
the transmit path to the antenna, so that the transmit  
signal can be transmitted on the antenna.

20 A third port is coupled to the receive path of the  
transceiver. The antenna coupled the antenna to the  
receive path, so that the received signal can be  
received by the receive path of the transceiver.

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An important function of the duplexer is to isolate the transmit signal from the receive path of the transceiver. The transmit signal is typically much stronger than the receive signal. Some of the transmit signal inherently gets down the receive path. But this transmit signal going down the receive path must be greatly reduced (or attenuated). Otherwise, the transmit signal going down the receive path will swamp, or overwhelm, the receive signal. Then the wireless telephone will not be able to identify and decode the receive signal for the user.

The required attenuation of the transmit signal going down the receive path is achieved at some expense. The duplexer also attenuates the transmit signal going to the antenna for transmission. This attenuation in the transmit signal going to the antenna is known as loss. It would be beneficial to reduce the transmit path loss in the duplexer.

Additionally, the duplexer typically must be large enough to accomplish the receive path attenuation of the transmit signal. Consumers are continually demanding smaller and smaller wireless telephones with more and more features and better performance. Thus, it would be beneficial to

reduce the size of the duplexer while maintaining or improving the transmit signal attenuation in the receive path and simultaneously maintaining or improving the transmit signal loss to the antenna.

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### Summary

Transceivers account for a significant portion of the cost, size and power consumption of wireless communication devices. The front end, including  
10 antennas, duplexers, diplexers, isolators, PA's, LNA's and their matching circuits accounts for a significant portion of the cost, size and power consumption of the transceiver. It would be beneficial to reduce the cost, size and power consumption of these parts, individually  
15 and together.

Briefly, the present invention provides a ferro-electric tunable duplexer integrated with one or more of the other parts. This combination is referred to herein as an antenna interface unit. More specifically,  
20 in addition to adding F-E tunability, the present invention integrates one or more of the above components on one substrate. The components are integrated on one substrate either by placing each

component, with the appropriate matching circuit directly on the substrate, or by direct fabrication of the component and matching circuit into or onto the substrate.

5        For example, in the case of integrating the PA, the isolator and the duplexer, the PA active device (e.g., GaAs FET) is placed directly onto the common substrate. As part of the integration of components, the matching circuits for the components may be  
10   patterned or placed on the common substrate. The matching circuits for the PA would be patterned or placed on this substrate. The isolator, if used, could be fabricated directly on this common substrate or mounted as a discrete component.

15        The matching circuit between the isolator and the duplexer would be patterned or fabricated on the substrate. The isolator would have its junction patterned on this substrate, with the ferrite puck, magnet and shield placed over it.

20        For purposes of integration, a stripline duplexer may be preferred as it would use the common substrate as one half of each resonator. Additionally, its length is shorter than a corresponding microstrip realization.

Whatever type of duplexer is used, any coupling and tuning capacitors would be patterned on the common substrate. It will be understood that the same kind of integration can be carried out for the LNA, duplexer and antenna matching circuits. If minimum loss is a key requirement for a post PA BPF, duplexer or multiplexer, then a low loss substrate must be used as is well known to those skilled in the art.

The topology of the matching circuits would be typical matching circuit topologies with two key exceptions: (1) they would be integrated with the other parts and matching circuits on the common substrate and (2) they may comprise F-E tunable components, though they need not all comprise F-E tunable components. The PA and isolator matching circuits would typically be pi matching circuits (shunt capacitor, series inductor or microstrip line, shunt capacitor). The isolator typically uses series or shunt reactive circuits. The duplexer and duplexer matching circuits would typically be simply series input and output capacitors. The antenna matching circuit would be a pi or T circuit with L-C ladders creating a higher order matching circuit. Preferably, the duplexer would be as claimed



in U.S. patent application 09/912,753 filed on July 24, 2001.

### **Brief Description of the Drawings**

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Fig. 1 is a block diagram of a side view of an antenna interface unit.

Fig. 2 is a schematic diagram of a power amplifier matching circuit.

10 Fig. 3 is a schematic diagram of an extended power amplifier matching circuit.

Fig. 4A is a schematic diagram of a multiband power amplifier matching circuit.

15 Fig. 4B is a schematic diagram of another multiband power amplifier matching circuit.

Fig. 5 is a schematic diagram of an isolator and its three matching circuits.

Fig. 6 is a schematic diagram of a LNA matching circuit.

20 Fig. 6B is a graph of a LNA noise figure response.

Fig. 7 is a schematic diagram of an antenna matching circuit.

Fig. 8 is a block diagram of an antenna interface unit.

Fig. 9 is a block diagram of an antenna interface unit.

5 Fig. 10 is a block diagram of an antenna interface unit.

Fig. 11 is a block diagram of an antenna interface unit.

10 Fig. 12 is a block diagram of an antenna interface unit.

Fig. 13 is a block diagram of an antenna interface unit.

#### **Detailed Description of Preferred Embodiments**

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Referring now to Fig. 1, an integrated antenna interface unit (AIU) 12 is shown. While a duplexer is shown, as is common in a CDMA handset, a multiplexer could be used as well. While the description that  
20 follows specifies a duplexer throughout, it is to be understood that a multiplexer or BPF could be substituted for the duplexer. A PA unit 20, an isolator unit 24, and a duplexer 28 are all attached to a common

substrate 16, eliminating the need for individual substrates for each of these components.

The substrate is preferably made of a carefully selected material. The substrate parameters that are typically critical are dielectric constant, loss tangent, thermal properties, cost and ease of processing. Typically, a dielectric constant should be less than about 40, and the loss tangent should be less than about 0.001 in the frequency range of interest. A low loss substrate may be more expensive than a higher loss substrate. A designer must frequently balance the issues of cost and performance parameters such as loss. Additionally, metal loss must also be minimized. A substrate must be chosen that can accommodate a low loss metal.

Advantages of integration of components with a multiplexer include: (1) reduction of the overall loss associated with the integrated device compared to that arising from using discrete parts, thus making it easier to meet specifications; (2) reduction of the footprint of the Tx chain in the sybsystem; (3) reduction of the overall parts count, especially as far as a manufacturer of a wireless communication device is

concerned; (4) reduction of cost due to reduced  
packaging and parts count, (5) integration of f-e  
tunable components with lower added loss and occupying  
less space than if introduced as individual, lumped  
5 element components.

A PA-to-isolator matching circuit 41, disposed on  
the substrate 16, couples the PA unit to the isolator  
unit 24. An isolator-to-duplexer matching circuit 44,  
disposed on the substrate 16, couples the isolator to  
10 the duplexer.

Preferably, an isolator is used, but it is  
optional. If no isolator is used, it will be understood  
that the isolator is removed and the PA-to-isolator  
matching circuit and the isolator-to-duplexer matching  
15 circuit is replaced by a PA-to-duplexer matching  
circuit. There are two main reasons a designer will  
choose to use an isolator in a design such as disclosed  
herein. The reasons are: (1) To provide a certain load  
impedance to the device preceding the isolator (the PA  
20 in this case); and (2) To prevent unwanted signals from  
propagating back into the device preceding the isolator  
(the PA in this case). Unwanted signals propagating  
back to the PA can cause unacceptable mixing or

distortion or both to be created which can render the overall design unacceptable.

As is well known in the art, there are many cases where the isolator can be eliminated. This is true when: (1) The PA can be presented an acceptable load under operating conditions; or (2) The isolator can be replaced by a suitable coupler or passive hybrid device that reduces the effect of reverse power propagation on the desired signal path. Passive couplers or passive hybrid couplers can be more easily implemented by direct fabrication on the substrate as outlined in this application.

This particular configuration of the AIU 12 is shown and described in detail for purposes of example and illustration only. The AIU 12 may not include a PA 20 or an isolator 24. As will be described more generally with reference to Figures 8-13, the AIU always has a tunable multiplexer and some other component on a common substrate. Other than that, there are many possible components that can be integrated with the multiplexer to form the AIU. The PA and isolator are just two examples.

Also, the PA may include multiple active devices. This is called a multi-stage PA. The discussion will be in terms of one active device, but it will be understood by those skilled in the art that this discussion could be applied to multi-stage PA's.

Since the matching circuits and components are on a common substrate 16, the impedance matches do not have to be to the industry standard 50 ohms. Instead, the impedance match can be from the natural output impedance,  $Z_o$ , of one component to the natural input impedance,  $Z_i$ , of the next component.

For example, referring again to Fig. 1, if the PA unit 20 has an output impedance of about 2.5 ohms and the isolator unit 24 has an input impedance of about 12.5 ohms, the PA-to-isolator matching circuit 41 will match the impedance from 2.5 ohms at the PA unit 20 to 12.5 ohms at the isolator unit 24. This is in contrast to the prior art. In the prior art, the PA unit would typically have its own substrate, and the isolator unit would typically have its own substrate. The PA unit would have its own matching circuit which would match from the output of the PA (e.g., 2.5 ohms) up to 50 ohms. The isolator unit would have its own matching

circuit which would match from 50 ohms down to the  
isolator (e.g., 12.5 ohms). There would be additional  
loss in the signal in this match up to 50 ohms from 2.5  
ohms and back down to 12.5 ohms from 50 ohms.

5       A further advantage in matching from the natural  
output impedance of one device to the natural input  
impedance of another device is that a simpler topology  
in the matching network may often be used when  $Z_o$  and  
 $Z_i$  are closer in value than they are to the industry  
10   standard 50 ohms, for example. A simpler matching  
network will result in less added variation due to  
component variation than does a more complex network.  
In the limit where, for example,  $Z_o = Z_i$ , no matching  
network is needed between adjacent devices in the  
15   signal path. In the prior art, each device is typically  
matched to the industry standard 50 ohms.

Referring again to Fig. 1, the duplexer 28 is a  
low loss tunable duplexer, as described in U.S. patent  
application 09/912,753 filed on July 24, 2001. Ferro-  
20   electric components such as ferro-electric capacitors  
are used to tune the duplexer.

The integrated antenna interface unit has  
significantly less loss in the transmit path than non-

integrated transmit chains. Integrating components, the PA, for example, eliminates lossy attachments, which are described in U.S. patent application 09/912,753 filed on July 24, 2001. Specifically, an electrical connection between the PA substrate and the common substrate is eliminated. In the prior art, the PA is typically manufactured on its own substrate. When a communication device is made, incorporating the PA, an electrical connection must be made between the PA substrate and the common substrate. Whether this is accomplished by surface mount technology (SMT), hand soldering, wire bonding, or some other attachment method, attachment losses are added. By mounting the PA directly on the common substrate, these losses are avoided.

Referring now to Fig. 2, a PA matching circuit 48 is shown. A PA 50 has an input 52 and an output 54. In a preferred embodiment, the output 54 is coupled to a first capacitor 56. The first capacitor 56 is also coupled to ground. The output 54 is also coupled to an inductive element 58. The inductive element 58 may be a lumped element inductor, a microstrip line, or any other inductive element known in the art. The inductive



element 58 is also coupled to a second capacitor 60.

The junction between the inductive element 58 and the second capacitor 60 forms the output 65 of the PA matching circuit 48. The output 54 of the PA 50 is also  
5 coupled to a bias circuit. The bias circuit typically comprises an inductor 68, a third capacitor 71 and a voltage source 74.

Another example matching circuit topology is shown in Fig. 3. The matching circuit 72 is similar to the  
10 matching circuit 48 shown in Fig. 2, except that the matching circuit 72 in Fig. 3 has an additional inductive element 74 and an additional capacitor 76. Also, the output 78 of this matching circuit 72 is at the junction of the inductive element 74 and the  
15 capacitor 76. Any or all of the inductive and capacitive components may be tunable.

It will be understood by those of skill in the art that different matching circuit topologies might be used to implement the PA matching circuit. In general a  
20 more complex matching circuit will allow for greater control in the match at the expense of added insertion loss (I.L.) due to finite component Q, as well as greater cost and increased board space.

Referring again to Fig. 1, the PA is placed directly on the substrate 16, and the matching circuit described with reference to Fig. 2 is fabricated directly on the substrate 16. The capacitors may be  
5 fabricated directly on the substrate 16 as interdigital capacitors, gap capacitors or overlay capacitors, as is well known in the art. By fabricating the PA unit 20, the PA-to-isolator matching circuit 41 and the isolator unit 24 directly on the same substrate 16, attachment  
10 losses are avoided, in addition to the previously described losses resulting from matching impedances up to and back down from 50 ohms. In the prior art, the separate substrates for the PA unit and the isolator unit must be attached electrically and mechanically to  
15 a common substrate or board. There are losses associated with attachment of these additional substrates. Finally, there is additional loss in the electrical line connecting the separate substrates on the common substrate or board. By combining the PA and  
20 isolator onto a common substrate these losses are eliminated or significantly reduced.

Referring again to Fig. 2, the capacitors 56 and 60 may be tunable, using low loss tunable ferro-

electric materials and methods as described in U.S.  
patent application 09/912,753 filed on July 24, 2001,  
and 09/927,136 filed on August 10, 2001, hereby  
incorporated by reference. This would reduce the loss  
5 even further, by providing for an optimum impedance  
match. The matching circuits shown in Figs. 2 and 3 are  
used to match a single band, such as the PCS band, or  
the cellular band. Presently, these matching circuits  
can achieve a tunability of at least 15%.

10 This allows for tuning even over several  
international PCS bands, such as from the India PCS  
band to the U.S. PCS band. To tune over a wider  
frequency, for example, from the U.S. PCS band at about  
1900 MHz to the U.S. cellular band at about 800 MHz,  
15 the PA-to-isolator matching circuit has to have more  
tunability.

For tuning a PA over more than one PCS band, the  
input matching circuit may need tuning as well. Whether  
tuning the input matching circuit is necessary or not  
20 can be determined on a case by case basis. The same  
technique as used for the output matching circuit is  
used in this case.

Increased tunability is attained by adding micro-electro-mechanical switches (MEMS) to the matching circuit. Referring now to Fig. 4A, a multiband PA matching circuit 31 is shown. The matching circuit 31 is similar to that of Fig. 2, except that several additional components have been added, with the ability to switch those components in and out of the circuit 31 with MEMS. The output 35 of a PA 33 is coupled, as in Fig. 2, to a first capacitor 37 and to a first inductive element 39. The first inductive element 39 is coupled to a second capacitor 43. But here, the output 35 of the PA 33 is also coupled to a first MEMS 45 for selectively coupling to a third capacitor 47. The first inductive element 39 and the second capacitor 43 are also coupled to a second MEMS 80 for selectively coupling to a fourth capacitor 83. These switches 45 and 80 and capacitors 47 and 83 change the capacitance of the matching circuit 31.

Additionally, the first inductive element 39 is coupled at either end to MEMS 86 and 89 for selectively coupling to a second inductive element 92. These switches 86 and 89 and inductive element 92 change the inductance of the matching circuit 31. In this way, the

matching circuit 31 can be used to match the PA 33 for  
use at either cellular or PCS bands. It will be  
understood that the techniques and devices described  
here could be used to match at other bands than the  
5 cellular and PCS bands. The cellular and PCS bands are  
chosen as examples. It will also be understood that  
other matching circuit topologies can be chosen.

Referring again to Fig. 4A, a multi band PA  
matching circuit 31 is shown which is similar to the  
10 single band PA matching circuit described with  
reference to Fig. 2. As stated the multi band PA  
matching circuit 93 has an advantage in that it is  
tunable over a broader range of frequencies, due to the  
addition of MEMS switches 86, 89, 45 and 80 and  
15 accompanying components. Tunable capacitors 37 and 43  
and tunable reactive element 39 can be used to fine  
tune over a specific frequency band. The specific band  
is selected by MEMS switches 86, 89, 45, and 80.

In addition to MEMS switches 86, 89, 45, and 80,  
20 the multi band PA matching circuit 93 has additional  
capacitors 47 and 83 and an additional reactive element  
92. Capacitor 83 is connected in series with capacitor  
43 and in series with MEMS switch 80. When it is

desired to switch to another band, such as, for  
example, another PCS band, MEMS switch 80 is activated,  
coupling capacitor 83 to capacitor 43 and reactive  
element 39 for changing the impedance of matching  
5 circuit 93. Similarly, MEMS switch 45 can be activated  
to couple capacitor 47 to capacitor 37 and reactive  
element 39 for changing the impedance of matching  
circuit 93. Also similarly, MEMS switches 86 and 89 can  
be activated to couple reactive element 92 in parallel  
10 to reactive component 39 for changing the impedance of  
matching circuit 93.

An alternative configuration of reactive  
components 92 and 39 and MEMS switches 86 and 89 is  
shown in Fig. 4B. In Fig. 4B MEMS switches 86 and 89  
15 are coupled to reactive elements 92 and 39 such that  
only one of reactive elements 92 and 39 is coupled to  
capacitors 37 and 43. Reactive element 39 can be  
switched out of the circuit, so that it is disconnected  
at both ends, whereas, in Fig. 4A, reactive element 39  
20 is always coupled to the circuit at capacitors 37 and  
43. Reactive element 92 only is switched in and out of  
the circuit. Note that in both Figs. 4A and 4B any of  
the elements 92, 39, 47, 37, 83 and 43 may be tunable.

At least one is tunable, but as few as one, or all of them, may be tunable.

For handset applications, the MEMS switches described here should have the lowest practical loss, e.g., DC resistance less than about 0.01 ohms. Switching speed is not critical so long as it is less than about 1.0 ms. Clearly, other applications may require other critical specifications on the MEMS switches.

Referring now to Fig. 5, an isolator matching circuit will now be described. An input port 97 is coupled to a PA (not shown), to a first impedance element 99 and to a second impedance element 101. The first and second impedance elements 99 and 101 form an input matching circuit for the isolator 95. The second impedance element 101 is coupled to ground, and the first impedance element 99 is couple to the isolator 95 for transmitting a signal from a PA (not shown) to the isolator 95. Both the first and second impedance elements may be ferro-electric tunable components, as described in U.S. Patent Application 09/927,136 filed on August 10, 2001.

An output of the isolator 95 is coupled to a third impedance element 103, which is coupled to a fourth impedance element 105. The third and fourth impedance elements 103 and 105 together form an output matching circuit and an output port 107 for the isolator 95. The output port 107 is coupled to a duplexer (not shown). Both the third and fourth impedance elements may be ferro-electric tunable components, as described in U.S. Patent Application 09/927,136 filed on August 10, 2001.

An isolation port 104, is coupled to an impedance element 109. The impedance element 109 is coupled to another impedance element 115 and to a resistor 118. Together the impedance elements 109 and 115 and the resistor 118 comprise an isolation matching circuit.

It will be understood by one of skill in the art that the input, output and isolation matching circuits described with reference to Fig. 5 using "L" matching sections are illustrative only. Other topologies for these matching circuits could be used, such as, for example, parallel LC circuits, "T", or Pi networks, as described in U.S. patent application 09/927,136 filed on August 10, 2001.



Advantageously, each of the impedance elements 99, 101, 103, 105, 109, and 115 are preferably formed directly on the common substrate described with reference to Fig. 1. This reduces losses associated with attaching separate units to the substrate, reduces cost and eliminates the need to match components up to the 50 ohm industry standard.

Regarding the PA, its characteristic output impedance for CDMA handsets is typically about 2-4 ohms near the maximum output power level required of it. The isolator characteristic impedance is typically about 8-12 ohms. Filters can be designed with input and output impedances that can take on a broad range of values. Since duplexers and diplexers are made primarily of filters, they can be designed to allow for a broad range of input and output impedances. Thus, they can be designed to match to whatever impedance is convenient based on the rest of the circuit.

Referring now to Fig. 6A, a preferred LNA matching circuit 117 will now be described. An input port 118 is coupled to a first inductor 121 and to a capacitor 124. The capacitor is coupled to a second inductor 127. The

second inductor 127 is coupled to a third inductor 130 and to an LNA 133.

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The matching circuits will be used to match the impedance between the various parts to avoid or reduce power loss in the signal travelling from one part to the other. For LNA applications, there is another purpose. For LNA applications, impedance transforming networks or circuits are used primarily to maintain an optimum noise impedance match between the input signal source and the active device chosen for the LNA. In fix-tuned circuits, the optimum noise impedance match is obtained at one frequency and is dependent on both temperature and component variations. In the tunable circuit approach described here, the optimum noise impedance match can be made adjustable to cover multiple bands or a wider frequency range than is possible in the fix-tuned case. An added advantage in using tunable components is the ability to compensate for temperature variations.

20 The introduction of f-e or other tunable components allows for increased flexibility in the design of LNA's. In the conventional design using fixed elements, one must usually trade-off optimum noise

figure and maximum gain. With tunable components, one can allow for cases where the input matching circuit can be varied from the minimum noise figure and the maximum gain, as desired.

5       A tunable optimum noise figure will now be described with reference to Fig. 6B. Fig. 6B is a graph showing noise figure 120 plotted against frequency 122. Typically, such as, for example, in a CDMA wireless communication device, there will be a maximum noise figure 126 specified for a given design of an LNA. The maximum noise figure specified is shown as a horizontal dashed line 126. A curve showing a typical noise figure response 128 is shown as the solid curve.

10       Typically, the LNA and its matching circuits will be designed so that the noise figure response 128 will be below the maximum noise figure 126 at an operating frequency,  $f_0$  130. A tunable LNA matching circuit allows the LNA noise figure response 128 to be tuned over frequency. The tuned noise figure response 132 and 134 is represented by two dashed curves of a similar shape to that of the typical noise figure response 128. By tuning the noise figure response at 132 and 134, the noise figure response can be made to be below the

maximum noise figure 126 at alternate operating frequencies  $f_1$  138 and  $f_2$  140. It will be understood that  $f_1$  138 and  $f_2$  140 are chosen as representative frequencies only. The noise figure response can be  
5 tuned over a broad range of frequencies. Additionally, it will be understood by one of skill in the art that MEMS switches can be added to the LNA matching circuit to further broaden the range of tunability of the noise figure response.

10 Referring now to Fig. 7, a preferred antenna matching circuit will now be described based on a CDMA handset. An antenna 136 is coupled to a first inductor 139 and to a second inductor 142. The first inductor 139 preferably has an inductance equal to about 8.2 nH.  
15 The second inductor 142 preferably has an inductance equal to about 3.9 nH.

The second inductor 142 is coupled to a first capacitor 145 and a second capacitor 148. The first capacitor 145 preferably has a capacitance equal to  
20 about 0.5 pF. The second capacitor 148 preferably has a capacitance equal to about 2.7 pF. It will be understood that other component values and matching circuit topologies can be used.

One side of the second capacitor forms an input and output port 149 for the antenna matching circuit for coupling to a diplexer (not shown), diplexer (not shown), multiplexer (not shown) or other type of filter  
5 (not shown).

The antenna matching circuit will typically be a pi or T circuit with an L-C ladder making it a higher order match. This gives more tolerance for impedance variation. Typically, the antenna in a system will be  
10 matched to 50 ohms. There may be, however, an ideal impedance for a given antenna that is other than 50 ohms, though 50 ohms is common for test devices.

For example, a commonly used antenna for wireless communication devices may have an input impedance of 30  
15 ohms. As previously mentioned, the PA may have an output impedance of about 2 ohms. The isolator may have an output impedance of about 12.5 ohms. The diplexer and diplexer filters can easily accommodate a wide range of impedances.

20 So the PA-to-isolator match is from about 2 ohms at the PA to about 12.5 ohms at the isolator. The isolator-to-diplexer match is from about 12.5 ohms to about 12.5 ohms. The diplexer is at about 12.5 ohms. So

the duplexer-to-duplexer match is about 12.5 to about  
12.5 ohms. The diplexer and diplexer inputs and outputs  
are at about the same impedance, for example, about  
12.5 ohms. The diplexer-to-antenna matching circuit may  
5 be a match from about 12.5 ohms at the diplexer to  
about 30 ohms at the antenna. Each of these matching  
circuits, plus the diplexer and the diplexer may be f-e  
tunable.

At mentioned above with reference to Fig. 1, it  
10 will be understood that a common substrate may include  
many different combinations of the parts mentioned  
above. In one embodiment, as shown in Figure 8, a  
common substrate 152 includes a duplexer 154, an  
isolator 156, a PA 157 and the requisite matching  
15 circuits (not shown). In another embodiment, as shown  
in Fig. 9, a common substrate 160 includes an antenna  
matching circuit 163, a diplexer 166 and a duplexer 169.  
In yet another embodiment, as shown in Fig. 10, a  
common substrate 172 includes an antenna matching  
20 circuit 175, a diplexer 178 and two duplexers 181 and  
184. In still another embodiment, as shown in Fig. 11,  
a common substrate 186 includes an antenna matching  
circuit 188, a diplexer 190, two duplexers 192 and 194,

two isolators 194 and 196, two PA's 198 and 200 and two LNA's 202 and 204. In another embodiment, as shown in Fig. 12 a common substrate 206 includes everything mentioned above with reference to Fig. 11, except the antenna matching circuit 188. In another embodiment, as shown in Fig. 13 a common substrate includes everything mentioned above with reference to Fig. 10, except the antenna matching circuit 175.

The integration of a PA module, isolator and duplexer for a CDMA TX chain removes the requirement that each stand-alone device be matched at 50 ohms at the input and output. By allowing for a more gradual impedance match (from about 2 ohms to about 30 ohms in the example given) one can reduce match-induced losses. Additionally, the f-e tunable components are exposed to a lower rf voltage, for a given power.

The reduced rf voltage, for a given power, reduces non-linear distortion, because f-e films are typically non-linear. Alternatively, a f-e component can be subjected to increased power while maintaining an acceptable level of non-linear distortion. Thus, designing integrated components that operate at lower input and output impedances allows for f-e components

to be incorporated in applications where higher power levels are required than possible with f-e components matched to the industry standard 50 ohms.

Fabrication on a common substrate further reduces  
5 losses that naturally arise when the components involved are packaged and mounted individually on a printed wire board (pwb).

By reducing Tx chain losses the Tx chain specifications can more easily be satisfied. This means  
10 that the specification for one or more of the parts involved can be relaxed. For example, the PA or other high value part specifications can be relaxed. A high value part is a part with one or more of the following characteristics: high cost, high performance, high  
15 level of difficulty in meeting specifications such as gain, power out, stability, ACPR, over temperature, and unit-to-unit repeatability.

Since the specifications on the PA, for example, can be relaxed, there are many possible benefits. For  
20 example, the PA may be able to meet specifications while consuming less power. This results in longer talk times or longer standby times or both. In another example, since Tx chain losses are reduced, a wireless



handset manufacturer may be able to meet specifications  
with a PA that has less stringent tolerances or  
requirements. The handset manufacturer may be able to  
choose a cheaper PA, reducing the cost of wireless

5    handsets. These benefits of reduced Tx chain losses are  
given as examples only. It will be understood by those  
skilled in the art that other benefits will arise from  
reduced Tx chain losses. It will further be understood  
that these benefits can be utilized to improve wireless  
10   communication devices in ways other than those  
mentioned here.